The Collins R-389/URR Receiver

Low Frequency Specialist

Part 1

by Ray Osterwald, NØDMS
PO Box 582
Pine, CO 80470

Early one Saturday evening last fall my phone started ringing. Putting down what I was doing and picking up the receiver, I heard a friendly voice on the wire say "Oh, hello, is the fellow who has been advertising all over everywhere for an R-389 PTO?"

When I sufficiently recovered and could remember how to speak, I replied that I was, but that I had nearly given up hope of ever finding one. The caller identified himself as Bruce, K6BLI, in California. He went on to say ". . .well, I'm afraid I don't have just the PTO, but I do have a complete receiver I would be willing to sell!"

We talked for quite a while, and ended up striking a deal. Through the courtesy and perseverance of Ray Mote (W6RIC), in a few weeks time I had what seemed a miracle: my R-389 on the bench, undergoing restoration.

Up to that time, I'd been collecting information and doing research regarding the R-389 and its history. At the same time, I was hoping to somehow find a PTO and get my parts unit restored. I'd gotten comments such as ". . . those receivers are extremely scarce, and parts even more so. . .", so I was getting pretty discouraged. The ultimate goal of the research was to do an ER article. The R-389 itself I wanted to use for medium wave DX'ing, which is more than a passing interest with me. Most of the information I had on hand to date was gathered over a long period to time from a variety of sources. These consisted of former Collins employees, surplus dealers, trade journal clippings, and the very few hams who have one, or who used to have one. One common theme with everyone I talked to was that they remembered the receiver, but had only seen maybe one for sale in their lifetime. Fair Radio Sales Company has been out of stock on these receivers for nearly 20 years.

Finally, one event occurred which really allowed this project to come together. Through an associate in Virginia, Mr. Charles Mylod, I was able to get access to a recently declassified Collins engineering report which had been stamped "restricted security information" for 32 years. It was apparently gathering dust in some forgotten file of the NSA, and in 1985 someone decided that 1940s thermionic technology really didn't need security protection. The report has detailed information about every phase of the project, and is the sort of "goldmine" I wish I could have found several years ago when writing about other Collins equipment. It is written, in places, in a first person narrative. Reading through the report is almost like being able to actually go up to Cedar Rapids, check in at the front desk, and visit with the engineers for a while to get background information for this article. The report is dated September 1953, and with the results of my restoration efforts, will form the basis of this article.

The Birth of the R-390 Series

In January of 1949, the Engineering and Research Division of the Collins

The Collins R-389/URR low frequency receiver.

Radio Company received a bid request from the U.S. Army Signal Corps Engineering Laboratory at Fort Monmouth, New Jersey. The Signal Corps "had big plans for the development of a series of receivers, similar in design, which would provide superior reception between the ranges of 15 kc and 3000 Mc". The initial proposal received in Cedar Rapids requested the development of two receivers, one tuning 15 kc to 1500 kc, and the other which would cover 500 kc to 32 Mc. The engineering managers held a series of meetings to further define what the Signal Corps was requesting. This resulted in Collins submitting a formal engineering proposal to them by March of 1949.

A few more discussions were had, more letters were exchanged, and pretty soon Collins had received a valuable Signal Corps Development Contract, number W36-039-SC-44552. This contract called for the simultaneous development of two new receivers, which the Signal Corps decided to designate the R-389 and the R-390. The technical specifications for these receivers were spelled out by the Signal Corps in document SCL-1134-B, which I have not been able to locate. The general outline of the specifications is indicated by reference in the engineering report, however. Collins accepted the contract, and formal work on the development project began in June of 1949.

It should be pointed out that this preliminary contract provided only for the engineering necessary to develop the new designs, and for 6 prototype receivers, 3 each of the R-389 and R-390. Actual receiver production was handled later under separate contracts. This article will frequently mention the R-390 because of the simultaneous development and certain design similarities of the receivers.

These two new designs, it was hoped, would fulfil many of the needs of the Armed Forces. The two basic requirements were "stability and calibration accuracy similar to other Collins equipment, notably the commercial 51J". The other main requirement was to combine into one receiver as many of "the facilities and special circuitry that are now being used by the various branches of the Army and which now require many different receivers to provide." Additionally, the contract called for development of special power supplies, cabinets, and a certain number of sets of "complete manufacturing drawings".

continued next page

R-389 from previous page

As the development plan was laid out, Collins came to realize that the Signal Corps was requesting receivers which were beyond the state of the radio art in 1949. In order to be successful, and to fulfill the contract terms, new materials, new processes, and advanced circuit designs would be necessary.

Undaunted by the obstacles ahead, Collins' senior engineers and top managers were assigned to this special development project and they dug right into the work. For the first time that I'm aware of, detailed information is available concerning the background of the men who were responsible for the development of this new Collins equipment. These men were:

Lou W. Couillard: Section Head, Medium Frequency Receiver Section

Couillard was a 12 years veteran with Collins, working almost entirely on receivers and receiving equipment. As a graduate of the University of Minnesota in 1938, Lou spent 1500 hours on the project in all phases in a supervisory capacity. He was responsible for the overall success of the project, and was the author of the engineering report which is the primary source of this article.

R. F. Witters: R-389 Chief Project Engineer

Apparently hired for the R-389 development project, Mr. Witters had prior experience with the Rauland Corporation (a defense contractor) and with the Galvin Manufacturing Corporation (now Motorola). He spent 4500 hours as the project coordinator and as a design consultant to the various speciality areas.

D.M. Lewis: R-389 Chief Mechanical Engineer

A graduate of Iowa State College (Art Collins' Alma Matter), Lewis had previous employment with the Curtis Wright Corporation in aircraft electrical systems design. He spent 4500 hours doing the mechanical design work for the R-389, which, next to the RF mixing scheme, was the toughest part of the entire project.

R.L. Stimson: R-389 Development Engineer, RF Subchassis

Stimson was a 1948 EE graduate of Indiana Tri-State College. He spent 600 hours working on the R-389 RF deck circuit design.

D.M. Hodgin: Development Engineer, PTO Design

A 1947 EE graduate of Purdue University, Hodgin, served two years in the Navy as a radio technician. Mr. Hodgin spent 900 hours developing the PTOs for the R-389 and R-390. The R-389 PTO was by far the most difficult PTO Collins ever built.

R. Craiglow: Development Engineer, Crystal Circuits

A 1947 graduate of Ohio State University, Craiglow gave two years service in the Signal Corps. He spent 200 hours designing the crystal oscillator, the calibrator, and the crystal filter circuit.

H. Stover: Development Engineer, BFO Circuitry

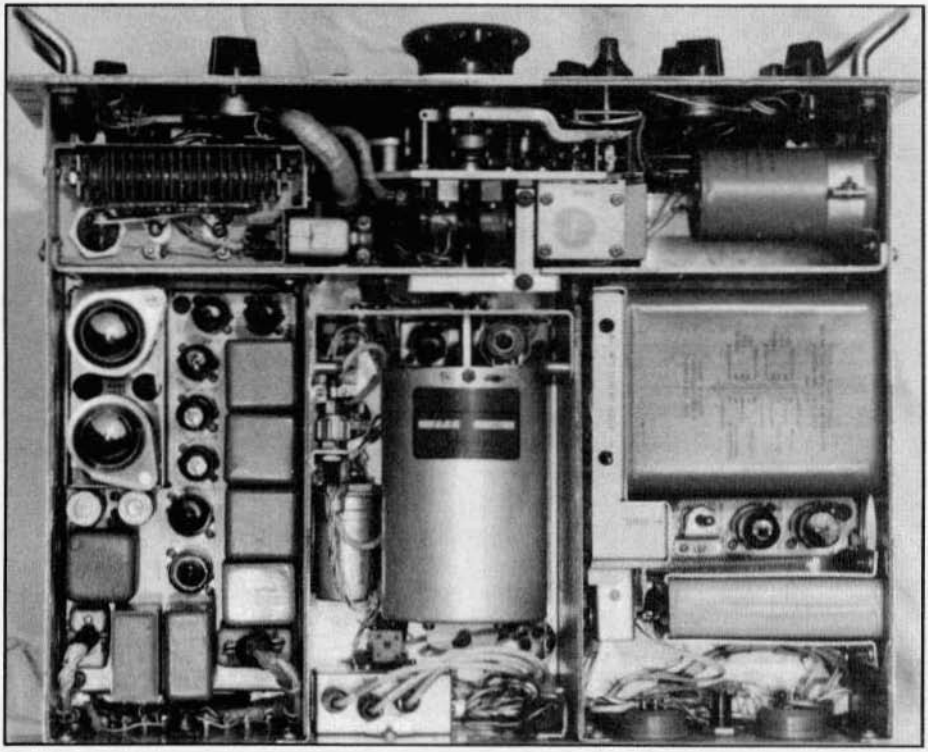
Stover graduated from Iowa State College in 1950. He had 2-1/2 years service in the Signal Corps. At Collins, he spent 300 hours designing the BFO circuitry.

R. Newmire: Development Engineer

An eight year veteran at Collins who came up through the ranks, Newmire spent 600 hours working on spurious response problems and overall system testing.

A.E. Eberhardt: Development Engineer, IF Subchassis Design

Eberhardt was a 1949 EE graduate from Purdue University, after serving two years in the Army as a Technical Sgt. He devoted 1500 hours to the design of the IF subchassis unit. Collins regarded IF performance as a critical function, due to the nature of the specifications.



R-389, top view.

N.E. Houge: R-390 Project Engineer

A 1950 graduate of the University of Wisconsin, Houge spent 3000 hours on the R-390 design. He is mentioned here because he designed the audio subchassis and the power supply units, which are common to the R-389.

The Development Contract

As stated before, the development project began in June of '49. However, the first prototype R-390 was not out the door until January 1951, over a year and a half later. How they spent all of this time, and how the design evolved, is a fascinating study of the "inner workings" at the Collins Radio Company. All together, Collins estimated 30,000 man-hours were invested in the project, including the lab technicians and drafting time. This is roughly the equivalent of one man working better than 15 years with no time off!

To put this schedule in perspective, the delivery of the remaining 5 prototype receivers shaped up as follows:

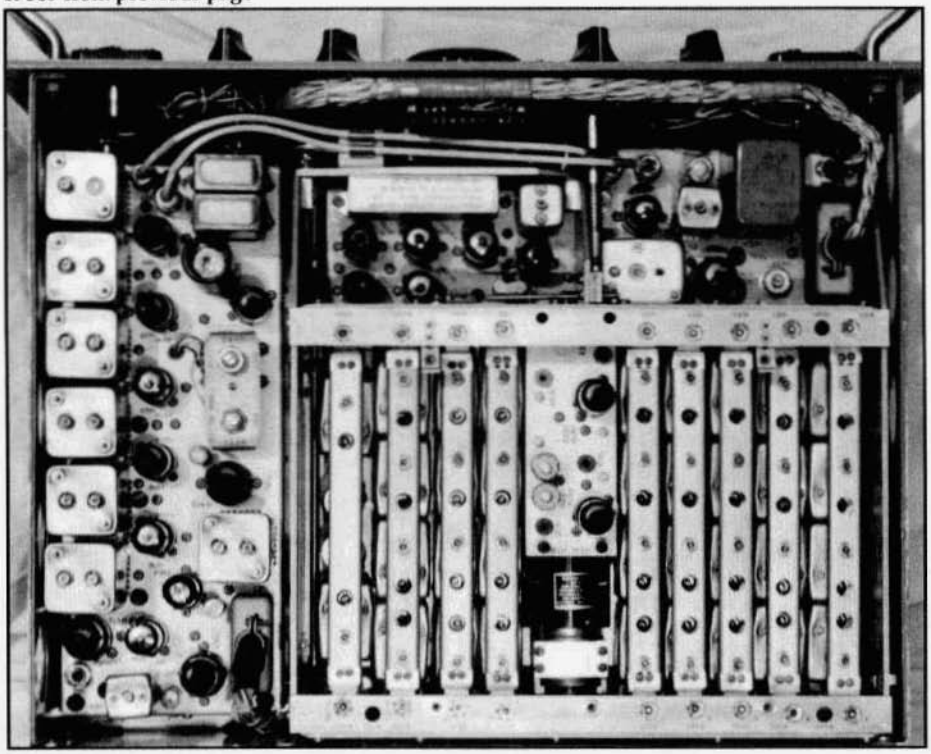
R-389 #1 - March, 1951
R-390 #2 - September, 1951
R-389 #2 & R-390 #3 - February, 1952
R-389 #3 - May, 1952
Accessories - February, 1953

Soon after the development contract was received, they decided the project would be broken up into three task areas: planning, model building, and the final report and drawings.

The planning task took the greatest amount of time, and obviously had to be completed before any models or prototypes could be built. Planning started with the electrical design. Mechanical design followed, as it generally depended upon whatever electrical requirements had been established. It's interesting to note that the word "elec-

continued next page

R-389 from previous page



R-389, bottom view.

trical" is used, not "electronic", when the report discusses design theory. This truly was the era of electric radio.

The contract called for one experimental working model of each receiver, which would be followed by two engineering models of each. The two engineering models would serve as a two-stage evaluation platform, so that any desired changes could be incorporated in a final production design.

Once all the planning tasks were complete, the model makers went to work. The model building department built a paper mock-up of the overall concept. This was used by engineering to visualize all the parts, to locate all the subassemblies in relation to one another, and to allocate the required amount of space.

The paper version was followed by actual breadboard modules which were "the first attempt to fit the required circuitry into the space allocated." These breadboard receivers, "while operational in some respects, were never completely functional, and were never delivered to the Signal Corps." They were secret, classified material and kept under guard at Collins.

From what was learned with the breadboard designs, work soon started on the first prototypes actually delivered to the Signal Corps. These were what they termed the "engineering models", one each R-389 and R-390. The first two were built in a rush, and Collins apparently knew about many problems and deficiencies in them. To compensate for these problems, the design of the second two was started even before the first units were taken to Fort Monmouth. This allowed them to get ahead a little bit, and keep the develop-

ment contract on schedule. The Signal Corps engineers were working very closely with Collins engineers during this time, so there "was a chance for many of the Signal Corps' opinions and changes to be incorporated in the second version before its delivery".

The third set of two models was done a little differently, however. They held off on delivery of the third set until the second models were completely evaluated. This allowed all of the changes brought on by Signal Corps evaluation to be built in. This took extra time and delayed the program, but "the result was a more complete design which was more acceptable to the Signal Corps". After acceptance of the third model, the design was "frozen", and not allowed to change.

It is interesting to speculate on the possibility of some of the prototypes surviving. In discussing R-390s with an east coast surplus dealer several years ago, he mentioned having a very old Collins R-390 that nobody wanted. This particular unit had an unusual front panel layout, and a different dial bezel. He indicated that the serial number and contract number were strange, and wondered if it might have been some kind of a prototype. I wish I knew what happened to that receiver, as I didn't take note of it at the time.

The final phase of the development project, the delivery of the final prototypes, was considerably delayed when the Signal Corps decided they liked what they saw and placed an unexpected order for production quantities of R-390s! This would put the first order for the R-390 in mid 1951, but the exact date is unfortunately not mentioned. Collins was now really under some pressure, as they did not consider the receiver to be ready for production, and had to divert engineers away from the development project. The development contract still had to be completed, and so to relieve the situation, Motorola was set up as a "directed subcontractor for a large quantity of R-390 receivers". Using Motorola this way allowed production and development to go on simultaneously, and finally explains why there are numerous early Motorola R-390s and relatively few Collins examples. It also might explain known subtle differences in early production R-390s.

I have never found any evidence that R-389s were produced anywhere but at the Collins Radio Company.

Collins knew there were many improvements which could be made even after delivery of the third model, but in the words of Lou Couillard, "In a development project of this kind where a group of engineers design and build a piece of equipment, there is one problem always to be faced. That is, to decide at what point in design work can be stopped and it can be definitely said that this is it. Of course, the design objectives and specifications should be the answer to the problem, but no good engineer who is striving for the optimum in his design likes to stop work when he can see further improvement possible even though minimum design objectives and specifications have been met. . ."

I think this summarizes pretty well the attitude of the Collins employees. They built receivers which changed the state of the art and were destined to outlive many other pieces of equipment, but they were still not satisfied and found it difficult to accept the lowest common denominator. What a contrast to the present! It seems like outsourcing, downsizing, layoffs, budget cuts and mergers have reduced morale to a point where it's amazing anything gets done. **ER**

The author welcomes correspondence about the R-389. Next month will feature part 2, the R-389 electrical design.

The Collins R-389/URR Receiver

Low Frequency Specialist

Part 2: Electrical Design

by Ray Osterwald, NØDMS
PO Box 582
Pine, CO 80470

Anyone who has seen or worked on an R-389 knows that it is a very complicated piece of equipment. While similar in layout and appearance to the R-390, it is quite different electrically. Although the R-389 is a superheterodyne similar in design to the 51J receiver, it can't really be said that it is conventional. The mixing stage is unique, and the story of its front-end design will be the focus of this part of the article.

Briefly, the electrical layout uses two RF amplifier stages, a double-conversion IF with a fixed crystal oscillator and a variable PTO, and a final IF at 455 kc. A frequency-locked loop is used to cancel drift, and the use of balanced mixers in the loop reduces noise and spurious response to levels that had not previously been possible. The IF, audio, and power supply subchassis are interchangeable with R-390 modules. There are 6 IF amplifier stages. The PTO can be tuned manually, or with a motor drive. This is a real help as the 70H-1 PTO is 50 turns! There are two tuning ranges selectable on the front panel, but actual bandswitching is handled by a switching motor.

The core of the R-389's performance, and the reason it was so difficult to design, is the mixing scheme. The mixers used are actually the fifth design, and the story of the steps involved in getting to the final version is fascinating reading for anyone interested in high-performance receiver history.

Before any serious frequency scheme planning could start, the Collins engineers had to determine the spurious response of various tubes when used as mixers. This turned out to be quite time consuming. They evaluated every available tube at all possible operating levels and compared all of the results. The best compromise formula turned out to be a remote-cutoff triode with balance in the plate output circuit to reject the local oscillator frequency. This produced a low mixer noise figure and reasonably good spurious rejection. For the R-389, a 12AT7 first mixer was chosen. The R-390 got a 6C4, which gave a 60 dB rejection to a fifth order.

Even though the tubes they would use had been determined by experiment, arriving at a final working schematic was a very difficult process involving many months of work. The design was dictated by the specifications, of course, and these strict requirements caused Collins engineers to push the state of the art in mixer design.

The Collins engineering report states: "Before any actual numbers for the signal ranges and injection frequencies could be decided upon, several design points had to be carefully considered. The most important of these were (1) spurious signals, (2) circuit complications, and (3) mechanical problems." The Signal Corps specification called out a maximum spurious level of 80 dB, so that is what they originally designed for. The Corps didn't put limits on mechanical complexity, but Collins knew that reliability and ease of maintenance would be very important to the Army. So, realizing that the mechanical linkages necessary to switch and tune a system that would meet the 80 dB limit would rapidly get out of hand, mechanical simplification was given top priority in all aspects of the planning process. You wouldn't know it to look at the finished receiver, though!

During the early stages of planning, frequency schemes were devised that would allow no spurious response below the 7th order. This is what the Signal Corps wanted, but when the mechanical systems didn't fit within their space limitations, the limit was dropped to 5th order. As anyone who has built high-performance receivers can testify, 5th order spurious response from tube circuitry is still very tough to achieve.

The decision to allow a 5th order spurious limit meant that the Signal Corps also had to give up the 80 dB total spurious specification. Engineering calculated that a 60 dB limit could be reached, and after some negotiation the Signal Corps agreed, and that became the design goal. At the time of the agreement, the engineers at Collins came to realize that there was no standard method to measure spurious response. Accurate spectrum analyzers and computer modeling tools which are taken for granted in 1996 had yet to be invented in 1950. They did have good signal generators and very accurate RF and audio voltmeters, so a procedure was agreed upon which used standard signal levels to measure an audio output response ratio. This method was accepted by the Signal Corps.

Originally, Collins considered only two types of spurious response in their design. The first response was the case of an IF frequency which was higher than the signal frequency, and the design would be such that signal harmonics got directly into the IF. The second spurious gremlin was when the signal, or its harmonics, beat with the injection oscillators, or their harmonics, and directly produced the IF frequency. A mixing scheme was cooked up on paper which held both of these possibilities to 5th order or below, and a breadboard version was built.

Why was the R-389 first IF selected to be 10 Mc and not some other frequency? The most obvious spurious response everyone learns about in radio theory class is when signal harmonics occur directly at the IF frequency. These must be greatly attenuated if you don't want to detect them. Past receiver work at Collins had shown that this response should not be lower than 6th or 7th order, which neatly coincided with the design goals. Simple arithmetic shows that if the highest signal frequency was 1500 kc, 7 X 1500 comes out at 10,500 kc. So, by using a 10 Mc IF, the lowest order harmonic would occur at 1428.6 kc.

Now that the 1st IF was selected, they were able to select the LO injection frequencies. This again is by arithmetic, the first LO being 8.5 to 9.985 Mc, and the second was 10.455 to produce the final 455 kc IF. The use of 455 kc at the second IF was called out in the Signal Corps specification.

Everyone looked good until one of the team members, probably Newmire, found a third and more serious type of spurious response which meant a total physical redesign of the mixers. This third type was an internally generated signal caused by the beating and mixing action of the various oscillators in the receiver. No external input was required to produce them. Once again, there was no standard for measurement of internal spurious levels. The procedure they designed compared the internal spurious level to an equivalent external signal and expressed the result in microvolts. The Collins designers wanted no internally generated spur to be greater than one microvolt, but found it extremely difficult to meet their own goal. Consider for a moment how tough this must have been. The R-389 tunes through its own IF frequency!

One may wonder why the R-389 uses two RF amplifiers, when one should be enough to meet any possible signal-to-noise requirements at VLF, especially when using low-noise triode mixers. The reason is, again, the tough 60 dB spurious level requirement. The mixer research performed earlier found it necessary to limit the maximum RF voltage at the first mixer grid so that the tube would not be

continued next page

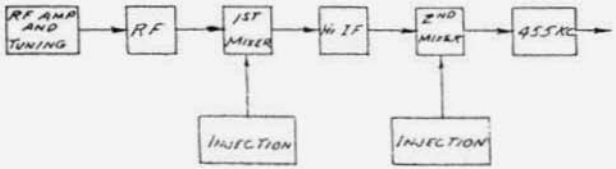


Figure 1

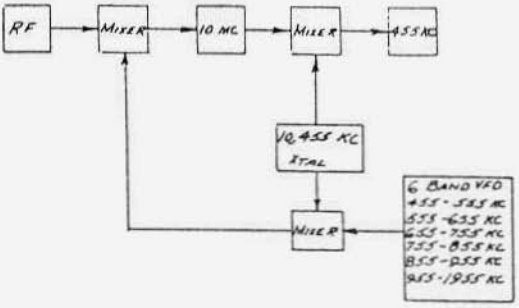


Figure 2

driven into distortion on strong signals. So, two AGC-controlled RF stages were used to do the required voltage limiting.

Nothing occurs without affecting something else. The decision to use two RF amplifiers meant the front end became more complicated. Since wide RF passbands were required in the Signal Corps specification, lots of RF selectivity is just what they didn't need. Due to the low frequencies involved and due to specifications, the front end of the R-389 was designed for a passband response. This set the number of RF coils at 4. A double-tuned circuit was used at the second RF amplifier plate because it was necessary to reduce the amplitude of harmonics generated in the tube, which were being directly coupled into the first mixer. The low end of the R-389s tuning range, 15 kc, is in the high audio range! All four of these coils, the antenna coil, the first RF plate, and the second RF grid and plate circuits are ganged and tuned via the front panel "frequency change" knob.

Finally, all the details were worked out from a numerical standpoint. Now, they had to get some working circuits with performance which would meet the numbers. Although the spurious levels could now be met on paper, the use of oscillator frequencies which were several times higher than the signal frequencies meant that the stability requirements could not be met using current technology. For example, if a VFO were designed to run directly at the first LO of 8.5 to 9.985 Mc, neither the stability or calibration accuracy requirements would be in tolerance. In addition, the second LO, even with the best available crystals and ovens, would have "marginal stability".

Originally, Collins wanted to use s slide rule dial for the R-389, similar to other current production receivers. The thinking was that 5 band segments of 100 kc each up to 500 kc, and one band for broadcast would be a nice frequency presentation.

Figure 1 is the first mixing design submitted for approval, and was taken from the engineering report. This original circuit had the first LO running from 10 Mc to 8.4 Mc, which meant an RF input range of 0 to 1600 kc. They built a breadboard version and tested it. The low fundamental crystal used in the LO caused so much trouble with spurious response that the design had to be ditched. So, the team went back to the library to research the problem and found some help in the 3rd edition of Reference Data for Radio Engineers. Still desiring to retain the slide-

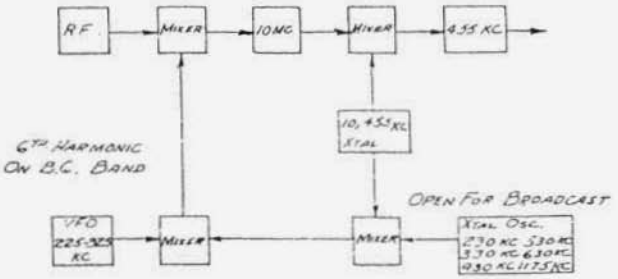


Figure 3

idea was scrapped.

Figure 3 is the third trial circuit design. Not much is mentioned about this particular design. They were still trying to retain the slide-rule dial, but not the 6-band VFO. Instead, this circuit called for two crystal oscillators. The high frequency crystal was still inside the loop, but was mixed with a low-frequency, bandswitched 3-crystal oscillator arrangement. The VFO was outside the loop, but since it was only necessary to run it at 225 to 325 kc, high stability could be maintained. While the report does not say so, I'm assuming this plan was scrapped because it didn't meet the internal spurious specification.

rule dial, the configuration of Figure 2 was tested.

The spurious response requirements meant that the originally determined oscillator injection frequencies could not change by more than a few percent. So, in order to maintain the required overall stability, it was decided to build the mixer chain as a frequency-locked loop. This would also allow the VFO to run nearer the signal frequency, further reducing drift.

Figure 2 shows ring mixer design number one. This setup used a six-band VFO, a crystal oscillator, and a loop mixer. By mixing the crystal frequency with the VFO inside the loop, crystal drift in one direction was cancelled by the mixing action at the other end of the loop, and the effect was constant second IF frequency. The circuit was built on a breadboard, and by using a signal generator for the VFO, many measurements were made. The spurious response results were "very encouraging". A request was presented to the oscillator department for the 6-band VFO system, which would have been necessary if the slide-rule dial were to be retained. The oscillator specialists evaluated the requirements and decided that it could probably be built and would maintain stability, but that it would be bulky. The space for the VFO, by this time, was predetermined. In view of the time required to built this new oscillator, and the space restrictions, the 6-band VFO

The mixing scheme used with the original 6-band oscillator performed so well that they had to retain it, if possible. With reluctance, the slide-rule dial was dropped in favor of a continuous tuning system and a counter dial. (Veeder-Root to the rescue!) This gives an input tuning range of 15 kc to 500 kc in one sweep, and by using the VFO's second harmonic, the broadcast band could be tuned with another sweep. Figure 4 is the outline of the final design.

At long last, Collins had a front end for the R-389 which met all of the specifications. The oscillator department went to work and developed the 70H-1 PTO, with a final tuning range of 469 to 980 kc.

Figure 5 is a detailed block diagram of the final mixing design actually used in production. The first mixer is single-balanced in the plate circuit. This is done to cancel the first LO frequency at the first mixer output, and to preserve the signal-to-noise ratio when tuning below 100 kc. This is necessary because, as the input frequency lowers below 100 kc, the injec-

continued next page

R-389 from previous page

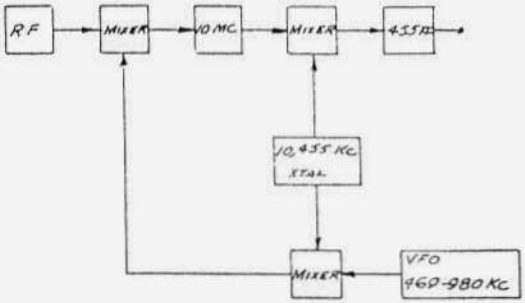


Figure 4

tion frequency approaches the 10 Mc 1st IF. Then, sideband energy from the oscillator then gets into the IF, causing phase noise at the detector.

The design was further refined by making the injection mixer double balanced, using two 6BE6s working into tracking, tuned output stages. This cancels the 10,455 kc LO signal, and is necessary to get rid of a spurious response at 455 kc, if the 10.455 Mc signal reaches the first mixer. The VFO "phase inverter" provides push-pull VFO drive to the 6BE6 mixers.

Balanced high-frequency tube mixers aren't stable no matter how hard one tries. An m-derived low-pass filter, having a cutoff of 50 dB at 10.455 kc, was included in the mixing loop. It further reduces the second LO voltage level into the first mixer. Its impedances are matched by a cathode follower on the input and a grounded-grid amplifier on the output. These are called "couplers".

The 1st mixer "driver" is a 6BH6 pentode, connected as a cathode follower. It provides the low impedance drive required by the cathode-injected 1st mixer.

Now that the front-end design was essentially complete, Collins had produced circuitry and test procedures which hadn't been used in this kind of receiver before, and had significantly advanced performance in several key areas.

Next month, electrical design continues with part three of the R-389 story. **ER**

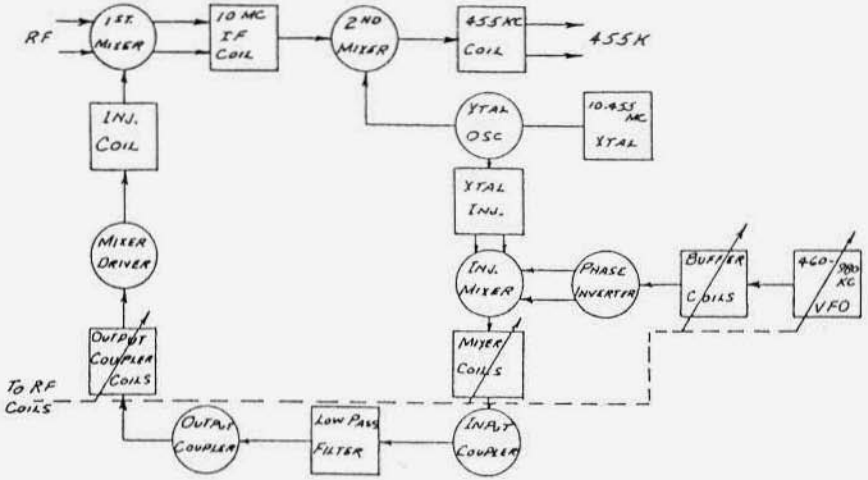


Figure 5
The Final Design

The Collins R-389/URR Receiver

Low Frequency Specialist

Part 3: RF Design

by Ray Osterwald, NØDMS
PO Box 582
Pine, CO 80470

The first two parts of the R-389 series have described the early development of the receiver, the engineers who were involved with the project, and the planning and electrical experimentation which went into the front end design. The third part of the R-389 series takes up the story at the RF deck.

The initial R-389/R390 development project ran on a deadline basis, so as soon as the conversion frequencies had been determined, design work began immediately on the RF deck. The design team knew that the RF unit would be the most complicated section of the receiver design from both an electrical and mechanical viewpoint, but little did they realize at the start just how tough it would turn out to be. Now that I know how much hard work and true innovation went into the design of this receiver, the more I stand in awe of their abilities when I peer down into the murky depths of an RF deck.

By the time the RF deck design began, the space that it had to fit was already determined. The final RF mixing plan required the use of a counter dial as a frequency indicator, so the PTO and the RF tuning arrangements also needed a linear frequency response. Also previously determined was the use of moving iron cores in variable pitch RF coils, as this was the easiest way to tune so many circuits in a linear fashion. These requirements changed into handicaps as the work progressed, but were overcome with some very innovative design work. Some of the results of this research are with us today.

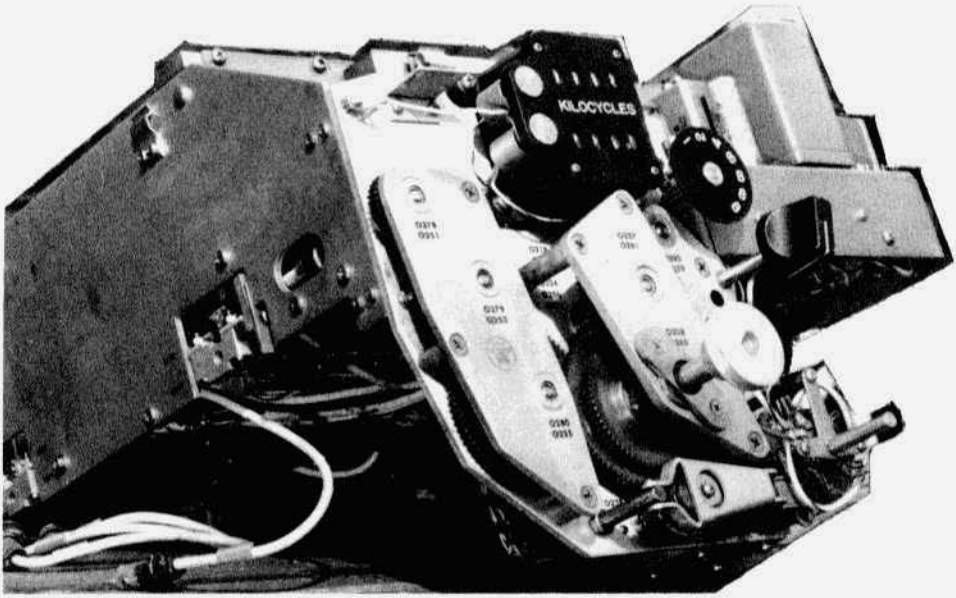


Figure 1. R-389 RF deck assembly.

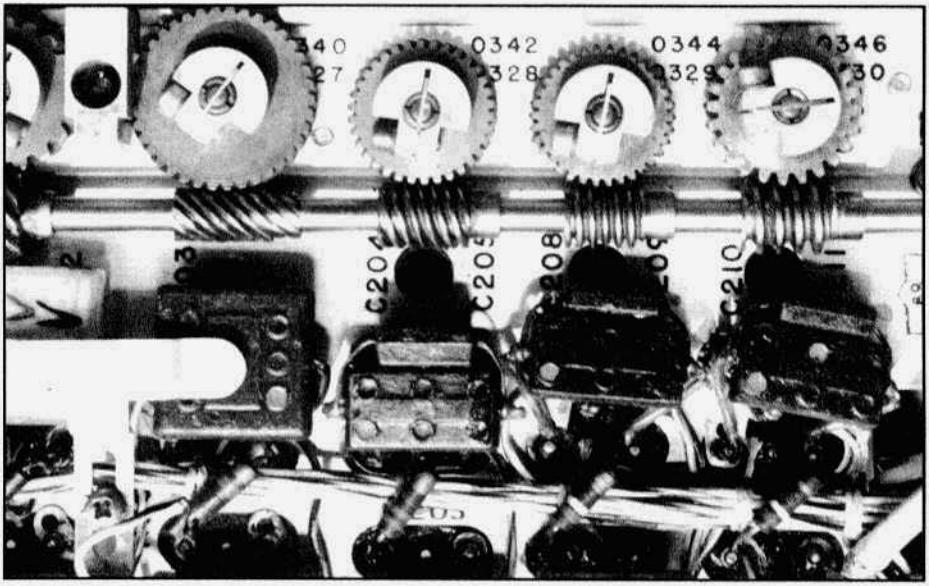


Figure 2. RF deck line shaft.

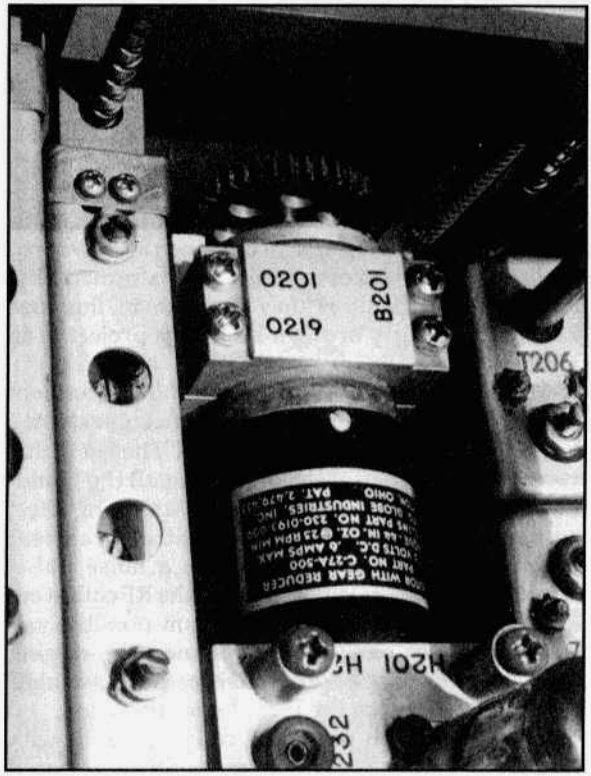


Figure 3. Top view of RF deck.

Up until the R-389, standard Collins RF designs used cam followers driven by rotary shafts to raise and lower spring-loaded slug racks. Iron slugs were attached to the moveable rack, and the up-and-down rack motion tuned the associated coil throughout the desired range. Early calculation found that about 1-1/4 total inches of motion would be required to tune the R-389 RF coil ranges in seven bands. Due to the limited space available, an attempt to use the standard cam design proved to be impossible. Some mechanical innovation was called for, and for a little while they remained stuck with no solution.

One never knows where the inspiration to solve a certain problem will come from. The key to the solution seems to involve having the ability to

continued next page

R-389 from previous page

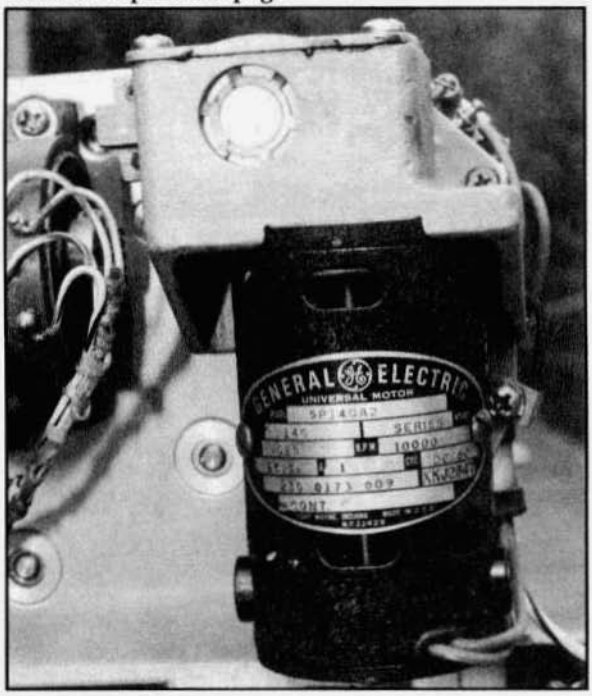


Figure 4. Tuning motor and cast aluminum drive box.

remain aware. Probably during a weekend fishing trip, one of the mechanical engineers got the idea of using parts from a level-wind fishing reel to provide the required tuning motion! Reversible horizontal line shafts geared to vertical lead screws were tried out. The vertical lead screws connect to the line shafts via spur gears, and helical threads on the vertical shafts are what actually drive the slug racks. The line shafts receive motion from the RF drive shaft, and the VFO receives motion from the VFO drive shaft. Both drive shafts are actuated by gearing, from either the tuning knob or the drive motor. This system worked well and limited available space. (Please refer to Figure 6.) Different gear ratios were designed into the system so that the racks could be moved at different speeds while being driven form the common RF drive shaft.

Figure 2 is a bottom view of the RF deck showing several worm gears and a steel line shaft. Notice the various gear ratio and drive pitch combinations. Figure 3 is a view of the top side of the RF deck, showing the bandswitching motor, several vertical drive shafts, and the slug racks. The bandswitch motor mounts to a machined aluminum drive block, which eliminates wobble and backlash in the band change system. Watching these vertical shafts and their racks in motion on an R-389 in good shape is almost as much fun as listening to it. Using the motor drive, the RF shafts spin real fast and move their racks up and down twice for only a half-inch movement of a mixer rack. The total effect is kind of like a miniature carousel without the horses.

Now that engineering had a usable frequency plan and a system which would provide the drive motion required in limited available space, the next step was to develop the powdered iron cores for the RF transformers. The difficulties they ran into in this area nearly brought the entire project to an end.

At the start of the development project, the Collins engineers evaluated existing VLF receivers. They felt that one serious shortcoming all the brand-X receivers shared was a ringing effect caused by short-duration transient surge energy, such as a noise pulse. They calculated that if the RF coils were built with the minimum possible values of Q and impedance, the ringing would be minimized and phase shift through them could be controlled.

Each of the RF coils was built with series pie windings, and the number of turns, spacing, and other parameters

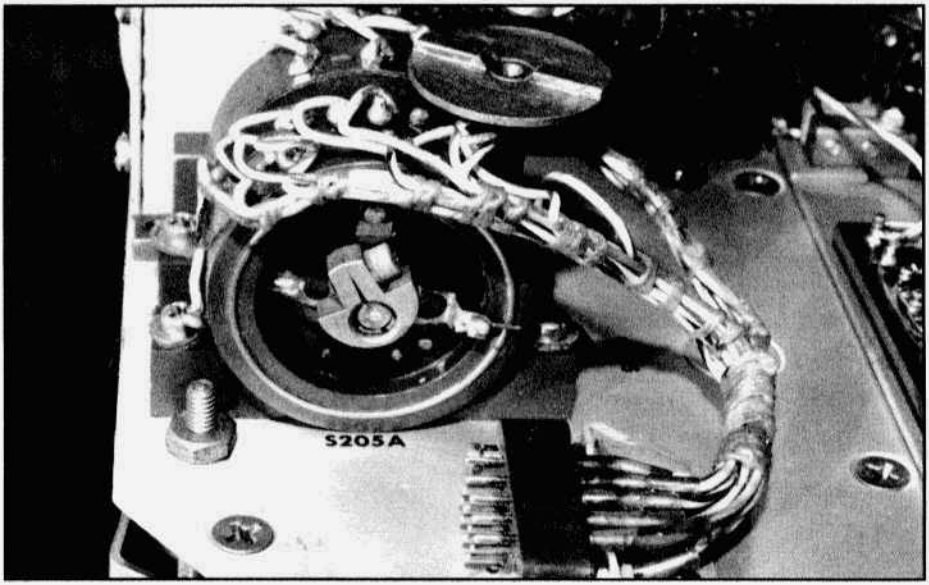


Figure 5. Bandswitch commutator.

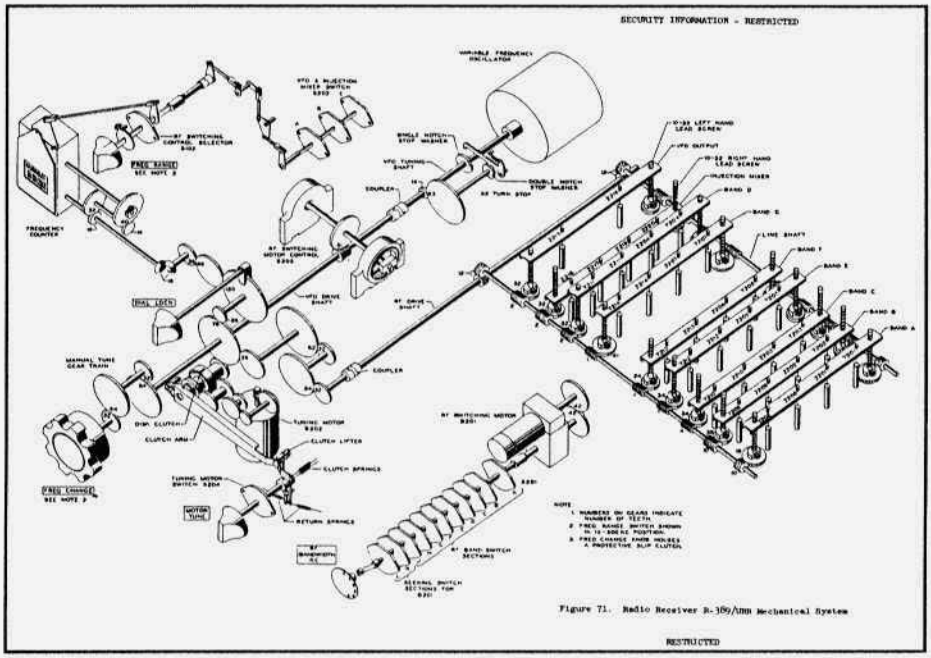


Figure 6. Mechanical drive system.

were determined by the desired linear tuning curves.

For the individual coil design, three main factors were of primary importance. The coil needed to have a linear frequency response versus coil insertion, because the counter dial readout was linear. There had to be a linear

continued next page

R-389 from previous page

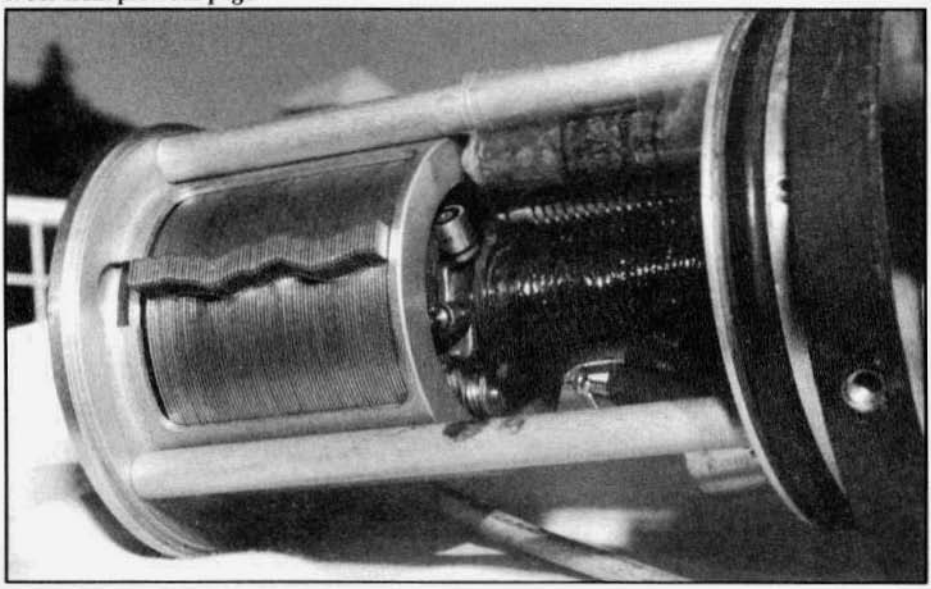


Figure 7. Interior of PTO.

frequency change versus Q change, and a constant coil impedance during frequency change. The last two were necessary because the gain across each band was not supposed to change by more than 1.5 dB.

It was found during lab experimentation that there was going to be insufficient spacing between the coil windings and the shield can. This shorted out the magnetic field around the coil - not a good result. It was necessary to use 28 RF coils, or 4 per band. The space which was available for the coils could not change, but without coil shields the RF deck would be useless. After a little more work, they discovered that by building special powdered iron sleeves which could be placed over the coil to serve as a magnetic shield, an electrostatic shield of aluminum could be placed directly next to the magnetic sleeve without any serious effects on coil performance. With this step out of the way, on they went to the actual core construction.

It was not difficult to find core material with sufficient permeability and loss characteristics to meet the design goals above 100 kc. However, when they went to the lower frequencies, they were presented with an "insurmountable problem". The iron core companies that they usually worked with called and said that they had given up trying to meet the specification, claiming that Collins was asking for the impossible.

In the tradition of the early radio experimenters, the Collins engineers had to start from scratch and invent something. These experiments "met with various degrees of success", to put it mildly. They began by reasoning that a core might be built in a manner similar to an audio transformer or a low frequency choke, with laminations built up from special iron. This was tried out, but the losses were too great. The Q disappeared at about 1/4 of the core insertion, and that idea was scrapped. Next, they built up a composite core by gluing iron transformer laminations to short pieces of powdered iron cores. By selecting various lengths of lamination and different powdered iron formulations, a wide variety of weird Q effects

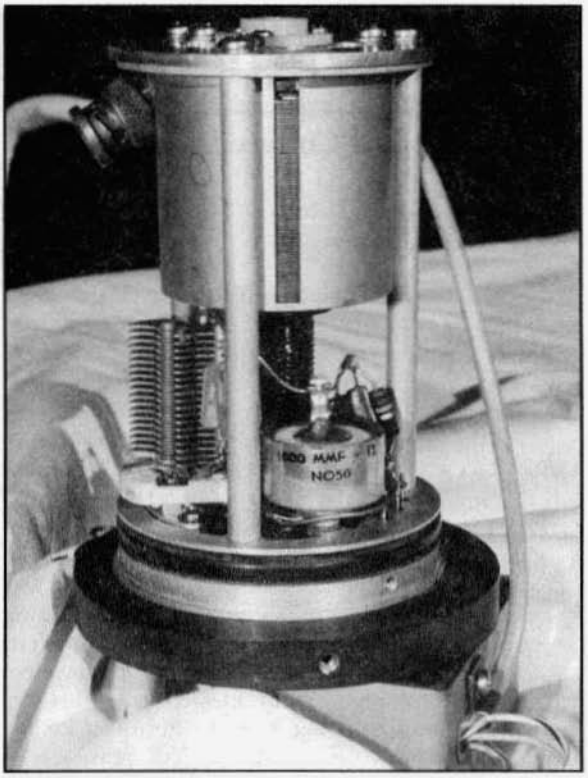


Figure 8. PTO showing precision ceramic temperature compensator.

could be obtained. By using special metals in the laminations such as "Audio A, oriented silicon, and others", the Q could almost be controlled. They couldn't figure out how to mass produce this special mix in the short time allotted, so the composite core was given up.

They went back to the cores they already had which met specifications at 100 kc, hoping to modify them somehow for the lower frequencies. This was done by wrapping copper bands around them at specific intervals. By varying the position, the width, and number of these bands, the Q factor could be controlled well enough to meet design requirements. Once again, no practical method of using this method in production was found, and everything again ground to a halt. Suddenly, somebody got the idea of using a conductive silver paint coating to replace the copper metal bands. A crash materials investigation started, and the winner was a Dupont formulation, number 4817. This was the breakthrough they had been looking for. While not producing an "absolute linear curve", the core could be produced in quantity. Once again, refusing to give up paid off. A new design with advanced characteristics was available, further advancing the state of the radio art.

While all of this coil design work was going on. Engineering Hodgin was over in the oscillator department working on the R-389 PTO. Work was started as soon as the frequency range and tuning speed were known, and it was hoped that it would be based on a standard PTO design with the relatively simple addition of a temperature control oven. It didn't quite turn out that way, and another special design became necessary.

The R-389 tuning rate had been set at 10 kc per revolution by other design factors. To provide this low rate, a leadscrew with a 40 pitch was necessary. This was much finer resolution than any other PTO ever built, and made the use of the standard corrector, or "cam stack" as hams call it impossible. A new radial corrector was developed which allowed differential movement of the PTO core. This is visible in Figure 7, an internal view of the R-389 PTO. The corrector consists of 50 circular stamped plates which are placed inside a machined casting mounted to the rear of the PTO frame. The slug rollers follow ridges inside of the assembly, al-

continued on page 38

R-389 from page 9

lowing for up to 115 degrees of correction. There is one corrector for every rotation of the 50 turn leadscrew. This much resolution was necessary because the clutch type zero adjustment of the R-390 was not used on the R-389 due to space and design limitations.

Due to the high tuning ratio of 2.09 to 1, a ferrite PTO core had to be used. Ferrite has high initial permeability, and its use was the only way to provide the required tuning resolution. In 1950, the temperature stability of ferrite materials was terrible. Not only was the coefficient high, but no two batches of material came out the same, which made production difficult. No vendor could supply what was needed, so several different approaches were tried. The first was to try to compensate for the poor temperature characteristic of the ferrite. They invented a mechanical devise which used "the differential expansion properties of materials" to compensate for the drift. It was apparently successful, but no sooner was this done when a new batch of ferrite was received. The new batch had exactly the opposite temperature characteristic! This was pretty frustrating, and meant that the new temperature compensator obviously couldn't be used. Since the new batch crossed over the zero drift reference, Hodgin reasoned that it was logical to assume some ferrite material with nearly zero temperature drift could be designed.

Working with in-house metallurgists, all new facilities to compound, fire, and test ferrite cores were built. In the end, this was successful but very expensive. Collins was able to lead the way for industry to "establish proper production techniques" for all types of ferrite core material. Eventually, three outside companies were able to produce small quantities of good cores with guidance from Cedar Rapids. Collins continued to work with them, and eventually was able to get larger and larger production amounts of stable cores. Some of the materials and processes invented by Collins during this period are in use to this day.

The last chore remaining with the RF deck was to build some kind of a bandswitch. It was determined by the mechanical engineers that any type of a conventional mechanical bandswitch system would need much more room than was available - a "monstrosity" is the way the report terms it! They came up with a clever motor-driven bandswitch and a two-section commutator, one section for each tuning range. The commutator has the "smarts" to be able to tell one band from another by the position of a sliding contact in relation to gaps on a fixed outer ground ring. When it is time to change bands, the sliding contact provides a ground to another selector switch located on the main bandswitch assembly. This runs the bandswitch motor until another set of bandswitch contacts determines that the proper RF range is reached and the motor stops. One section of the bandswitch commutator is pictured in Figure 5. There is a front panel knob which selects RF ranges of either 15 kc to 500 kc, or 500 kc to 1500 kc. In the low range there are actually five bands used, and two in the high range. Bandswitching is transparent to the operator except for a small "whirrr" sound when the end of one band is reached. It's like robot logic; the receiver mutes momentarily, and comes to life again on the next band.

The three prototype R-389 receivers had alignment oscillators built into the RF deck. These were necessary, according to the report, because signal generators of the time were "notoriously inaccurately calibrated" at VLF. Because of the low Q RF coils, accurate alignment is pretty difficult. Small errors in RF alignment will produce large errors in the bandpass characteristic of the receiver front end. This oscillator was not used in production models as far as I can determine. ER

Next month, part four of the R-389 receiver story.

The Collins R-389/URR Receiver

Low Frequency Specialist

Part 4: IF Amplifier Subchassis

by Ray Osterwald, NØDMS
P.O. Box 582
Pine, CO 80470

The next challenge for Collins was to design the IF subchassis, which is common to the R-390 and R-389 receivers. As mentioned in part one of this series, over 1500 hours was spent on the IF circuit design, and after reading through the fine details of what went on, I can understand why it took so long. IF amplifier design work was completed September 23, 1952.

The R-390 specification called for six selectivity positions, established by variable coupling in the IF transformers, and a single-crystal filter for the 100 cycle and 1 kc positions. It's interesting to note that the 100 cycle position has a quoted -6 to -60 dB shape factor of 1:48, which is genuine rotten selectivity. I don't know why they even bothered with it, except for maybe that's what the army wanted. There were certainly better CW filters around in '52. The only point on the curve with a 100 cycle bandwidth is at -6 dB, and the thing is actually broad enough to copy phone signals. This is why the sharp audio filter was included for the narrow-band modes. That high-Q audio filter is extremely tiring to use for long periods because it rings so much. I'd rather use almost any other receiver, including a regen, for CW. The wider positions, on the other hand, are really nice for AM phone or broadcast. The 8 kc position has a 1:1.91 shape factor and 16 kc has a 1:1.82 factor. This makes for high selectivity, but the ringing associated with high-Q mechanical or crystal filters is gone. I'd rather use the R-389/R-390 for AM-type reception than anything else. The widest bandwidth available was originally set up at 20 kc. This was later changed to 16 kc, but no mention is made of why the change was made.

The army also included a specification for envelope phase delay through the IF amplifier. It was originally thought that R-390s would be used in direction finding applications, so they wanted to control phase shift. Envelope phase delay is a critical parameter one finds when working with data circuits, but inclusion into a general coverage HF receiver specification is unusual. The "envelope" is whatever frequencies are passed within the -6 dB bandwidth of an amplifier, and the "phase delay" means that this group of frequencies should not be shifted in phase after passing through the circuit by no more than the prescribed amount. The actual requirement was that a 150 cycle modulating signal at the IF would not vary by more that 1/4 degree (4.63 microseconds) over the top 3 dB bandpass. They wanted this tight requirement in the 2 and 4-kc positions, but it was shown mathematically to be impossible, so the specification was rewritten for the 2-kc position only.

The IF amplifiers were entirely designed on paper before being tried out experimentally. The experimental results met the design perfectly, leaving very little to be determined by trial and error. Widely published universal design curves of the period showed that 30 (!) critically-coupled transformers

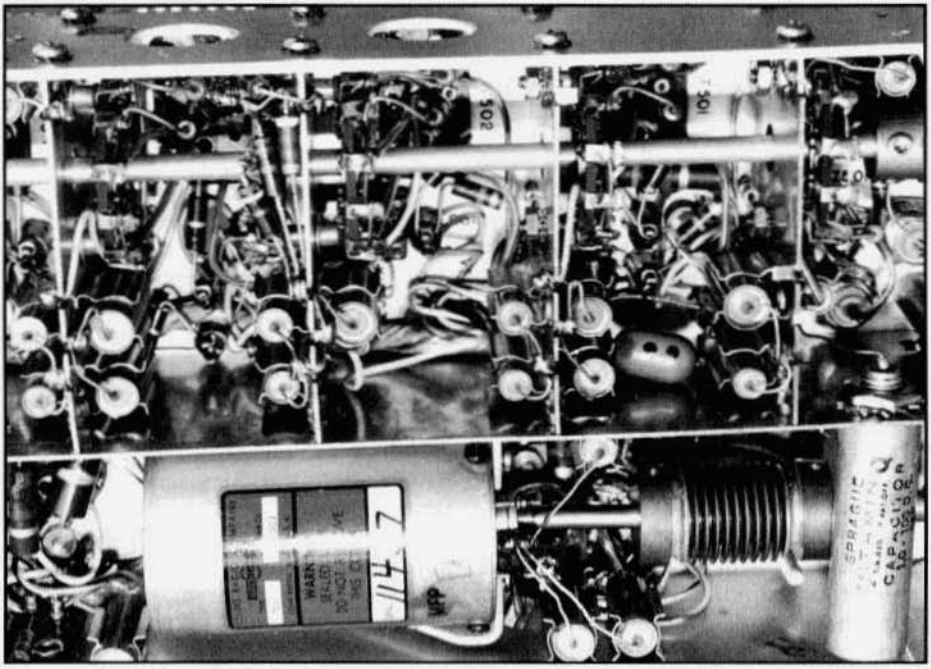


Figure 1. Bottom view of the IF subchassis. Notice the use of Sprague "Vitamin Q" capacitors for all of the bypass points. They are secured with separate clips which are screwed to the side walls. Although I'm sure there have been failures, I've never found a bad Vitamin Q cap in any equipment I've ever worked on.

would be required to get a shape factor of 1:1.9 at an 8 kc bandwidth. Other engineering work at Collins had shown that it only requires 4 transformers coupled at 3 times critical to get the same shape factor. The final design included four transformers at .6 times critical coupling for shape factor, and one critically-coupled "fill" transformer to meet the phase delay specification. To properly design an IF amplifier to meet some phase delay specification, the phase shift must be calculated to four or more decimal places over all five transformers. This type of work was extremely time consuming in 1952, as digital computers were not yet available. Previous work at Collins by an engineer named R.E. McCoy produced an empirical design method based on numerical equivalence between single-tuned and double-tuned circuits. Using McCoy's method and other graphical solutions, the exact design of the IF transformers was arrived at, and the lab breadboard version met the goals. Not too bad for a wooden calculator and a piece of paper, huh?

The IF amplifier gain requirement was set at 91 dB into the detector. To compensate for component aging, overall IF gain could be varied 20 dB with a pot located in the cathode circuits of the 3rd and 4th IF amplifiers. The design specs called for a linear output in the manual gain position for a 20 dB rise in voltage from "normal" levels. The 6AK6 pentode will handle a relatively large voltage input swing without being forced into grid current, and that's why they used it at the last IF amplifier position instead of another 6BJ6. The overall signal gain from antenna to detector is roughly 105 dB.

continued next page

R-389 from previous page

The IF transformers were another special design, and the coils were produced entirely at Collins (see figure 2). The windings were high Q, high impedance pie-type coils built up of many turns. The army insisted that the coils stand up to a 48 hour session in a chamber at 95% relative humidity and temperatures ranging from 20 to 65 degrees C. Many waxes, cements and casting resins were tried out in an attempt to seal the coils against this abuse. The report lists 16 different materials which were evaluated, and the best formulation was apparently a type of casting resin called "Araldite Resin F". Being a resin, two chemicals had to be mixed up in a batch before they could be used. The coils had to be hot dipped in this goop above 140 degrees F. A long cure time of 48 hours at 212 degrees F was required. I'm sure this was a smelly, dangerous process but the result was outstanding resistance to moisture in the coil assemblies which lasts to this day. After everything was assembled and the IF deck was in final test, it was found that any detuning caused by environmental changes was in iron core permeability, not in the coils! They were tested at 95% relative humidity and between -104 and +140 degrees F. Kids, do not try this at home!

Also located on the IF chassis is the 3TF7 ballast tube which regulates filament current by controlling the filament temperature of the oscillator tubes in the R-389, R-390, and the R-390A. This tube has been the subject of much controversy. The engineering report has the following to say about the 3TF7: "... Considerable work was done with Amperite Corp. in designing this special ballast tube which feeds a constant 300 mils to the two 6-volt, 300-mil oscillator tubes used in the VFO and BFO. These three tubes are connected in series across the 26-volt filament supply. The ballast tube (3TF7) operates on a current of 290 to 330 mils and holds this current within +-10 mils for input voltage variations of +-15%. This reduced the 15% variation to approximately 3%. There is some question if a filament regulator is necessary in these receivers since the oscillators are very good even without regulation. However, since the stability was a big factor in this design and since the factor of tube aging was not known, the regulator was included."

I guess that settles the question of whether or not the 3TF7 was designed specifically for the R-390.

The R-389 suffers from the same AGC attack time problem as do the '390 and '390A receivers. Originally, they used AGC on the two RF stages and the first two IF amplifiers. Bias was adjusted so that the audio output level only increased 6 dB (twice as loud) for a 106 dB increase in signal level. That's not too bad of an AGC control range. Unfortunately, it was found that strong signals were reducing the signal-to-noise ratio. Remote cutoff pentodes are noisy, and really strong signals would increase the bias so much that the"shot noise" in the amplifier chain was much more noticeable. To correct the situation, AGC control was moved from the second to the fifth IF amplifier. The first RF amplifier was changed to a 6AJ5 to reduce cross-modulation, but that tube has different AGC characteristics. These changes resulted in a loss of AGC control at signal inputs over .1 volt RMS. A tenth of a volt is a heck of a strong signal, roughly 60 dB over S9. This input level is rarely found except when your station is co-located with adjacent transmitters. The designers were therefore more concerned with the total range of AGC control rather than the attack time problem when listening to weak CW signals in the presence of strong ones. In any case, these receivers were mostly used in point-to-point service with constant-carrier transmissions.

The reason an AGC amplifier was used was simply to isolate the devel-

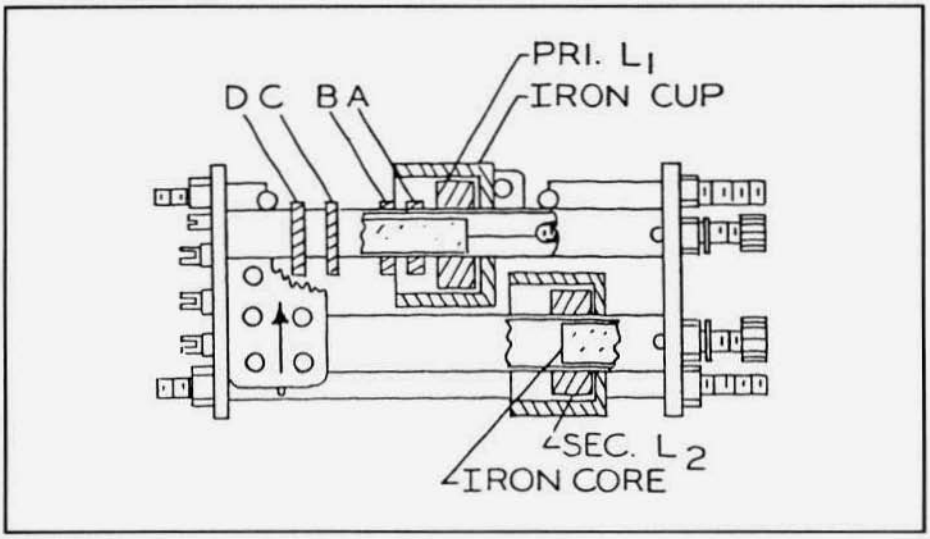


Figure 2. Engineering drawing of an interstage IF transformer. The letters A thru D are not identified.

oped AGC voltage from BFO injection.

No AGC was ever used on the mixers because their bias voltages had been carefully adjusted for the best spurious rejection ratio. Users restoring R-389s should carefully check these bias values to make sure they are within the 10% specification. Also, if spurious response problems are found and the operating voltages seem to be correct, try swapping out the mixer tubes with other new ones.

Restoration

I was lucky with my receiver in that it needed nothing major to get it going. The ballast tube was open (of course), but other than that it needed only routine cleaning, lubrication, and alignment. I didn't even have to replace any other tubes. I repainted my control knobs and meter housings with jet black Krylon.

Correct lubrication is critical on the R-389. The front mechanism plates carry 12 ball bearings which accept the tuning shaft journals. These bearings must be very clean and properly doped with load-bearing lubricant. Following the good advise of KDØHG, I've used Mobil Oil Company's synthetic automatic transmission fluid with very good results. Synthetic lubricants are far superior to petroleum-based oils, and should last forever in radio equipment. If the entire tuning system isn't free to turn, the motor drive life will be shortened, and you will need the motor. Just try to find a replacement if you burn it out! Some owners I've talked with have units with chronically stiff tuning mechanisms. This is due largely to years of neglect, and the ball bearings have gotten rusty. The only way to restore this kind of problem is to entirely dismantle the two front plates and have a machinist remove and replace the bearings. They are standard machine sizes, but an arbor press is used to change them. After lubrication, keep the receiver covered when it's not in use.

If the bearings are clean and lubed but there is a bind over a portion of the tuning range, there probably is an alignment problem between the front panel and the mechanism plates, or some other kind of mechanical damage.

There is a cast aluminum drive box attached to the tuning motor. It is actu-

continued next page

R-389 from previous page

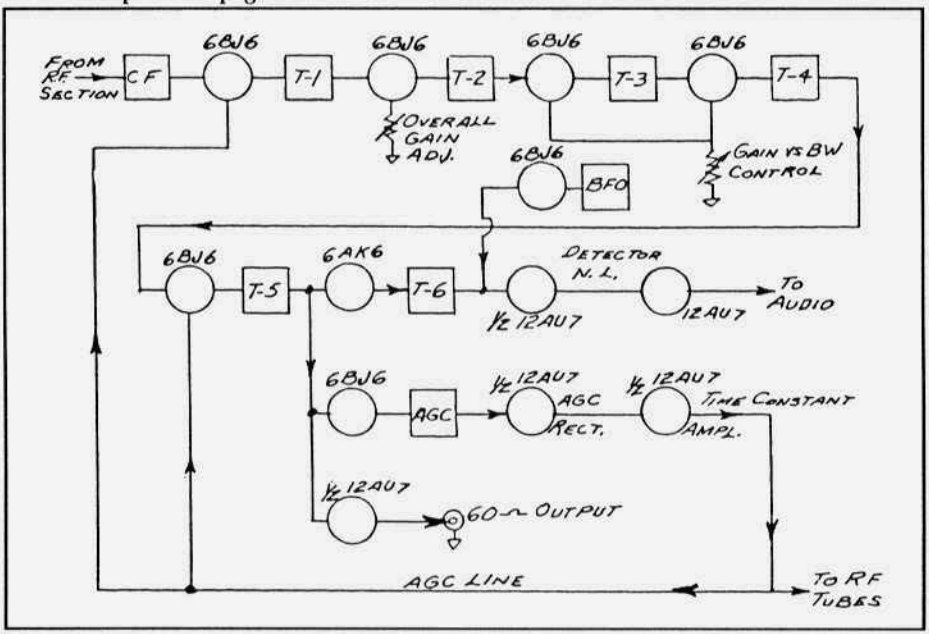


Figure 3. IF subchassis block diagram.

ally a differential drive, and is filled with lubricant and sealed up. I wanted to change the lubricant and check it out mechanically, but I couldn't get the cover off by removing the screws and gently prying at it. The sealant they used in production is really tough stuff, and everything I ran into said "stay out". Unless you really want trouble, I'd advise against tearing into the drive box under any circumstances!

Another likely area of trouble is in the selenium rectifier stack used for the bandswitch motor power supply. These old rectifiers can get kinda tired after 40 years. One of their favorite tricks is to not produce the same amount of DC after they warm up as when cold. The stack can be replaced with silicon diodes, but series resistors must be included so the DC voltages come out correct. The diodes can be disguised with heat shrink and hidden behind the old rectifier so that the unit at least looks original.

The mechanical alignment is extremely tedious. The manual calls out a procedure where a thin wire is stuck through holes in the tops of the vertical drive shafts to check slug rack positioning at certain frequencies. Doing this procedure nearly caused me to go permanently cross-eyed, but I found three bands where someone had managed to mess up the alignment.

Accurate RF alignment is important. It's hard to see much of a change on a VTVM when the RF alignment procedure is followed, but persistence is necessary in order to get everything tracking properly, the right amount of gain, etc. It helps to use a frequency counter to make sure the generator is where the dial says it is, unless you've got a newfangled one that's synthesized.

Modifications

If I did have any modifications for the R-389, I'd sure never publish them. I only modify command sets and R-390As.

Performance

I've heard the R-389 called the "Holy Grail" of medium-wave DX'ers. I never really knew what that meant until I

continued on page 41

R-389 from page 8

tried one out. I guess my performance conclusion is that the receiver definitely shows off the attention to detail that went into its design.

At my location, the R-389 seems to be completely free of any sort of detectable intermod product. For example, in broad daylight when the groundwave is the strongest and receiving from a broadside, full-wave wire antenna cut for the center of the broadcast band, there is no detectable product at 1140 kc, the 3rd order mix between KOA at 850 and KLZ at 560 kc (mixing product = (2 X 850) -560). These stations are powerful, longtime Colorado clear channel broadcasters. This test was made with my headphones on, the receiver AGC in the manual gain position, and the RF gain control at full tilt. There is no second-order mixing going on at 1410 kc between these two, either. There is no detectable mix between powerful AM broadcast stations and the receiver's local oscillators. I've never been able to detect any kind of image response (images tune "backwards" from real carriers). Tuning around with the antenna disconnected and the BFO on does not reveal any birdies, even when tuning through the IF! The receiver does not block up or overload when receiving the 50 Kw station in Louisville, Kentucky at 840 kc, the next channel down from the KOA powerhouse at 850. Yet, the receiver is so sensitive that at night in midwinter I can hear foreign carriers between the U.S. AM broadcast allocations, occasionally with a little bit of modulation on them.

At the time I checked it, my R-389 met or exceeded all of the specifications published in the Army technical manual. Due to differences in test equipment configurations and individual experience, interpretation of receiver test results can vary wildly. I'm not going to write up any more numbers relating to equipment performance.

This concludes the R-389 series. Readers wishing to obtain their own copies of the Collins engineering reports should write to Mr. Frank Gentges, (AK4R), 9251 Wood Glade Dr., Great Falls, VA 22066 for further details. **ER**

The Radio VT Fuze from page 15

2. Generator-Powered Proximity Fuze, R.D. Huntoon and J.B. Miller, Electronics, pg. 98-103, Dec. 1945.
3. Proximity Fuzes for Artillery, H. Selvidge, Electronics, pg. 104-109, Feb. 1946.
4. The Radio Proximity Fuze, Henry M. Bonner, Elect. Eng., AIEE, Vol. 66, pg. 888-893, Sept. 1947.
5. Introduction to Radar Systems, Merril I. Skolnik, McGraw-Hill Book Co., Inc., 1962.
6. The VT Fuze of World War II, William Denk, W3IGU, The Antique Radio Gazette, Vol. 18, No. 1, spring, 1990.
7. Letter from H. Selvidge, June 27, 1996.
8. "The Deadly Fuze", Ralph B. Baldwin, 1980, Presidio Press, PO Box 3515, San Rafel, CA 94902.
9. Electronic Umbrella Protects U.S Troops, Bruce D. Nordwall, Aviation Week and Space Technology, p. 90, Feb. 5, 1996.

ALL OUR SAFETY BELTS ARE IN FOR REPAIR--- MAYBE THIS WILL BREAK YOUR FALL